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NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-0360-78
INFRARED RADIATION HAZARD
EVALUATION OF THE ROTARY FORGE
WATERVLIET ARSENAL
WATERVLIET, NEW YORK
MARCH - APRIL 1978

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(10) Wesley J. Marshall

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The rotary forge at Watervliet Arsenal was surveyed for infrared hazards on 9-10 March 1978. It was found that levels of infrared exceeding protection standards for 10-second exposures were present at distances less than approximately 3 meters from the radiation source. This radiation would, however, be easily detected by exposed personnel due to body heating and would not, therefore, present a serious health hazard due to whole-body heating. However, eye protection against infrared was deemed necessary due to possible cataract formation from repeated exposures.

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ABERDEEN PROVING GROUND, MARYLAND 21010

Mr. Marshall/lr/584-3932

7 JUN 1978

HSE-RL-L/WP

SUBJECT: Nonionizing Radiation Protection Special Study No. 42-0360-78, Infrared Radiation Hazard, Evaluation of the Rotary Forge, Watervliet Arsenal, Watervliet, New York, March - April 1978

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A summary of the pertinent findings and recommendations of the inclosed report follows:

The rotary forge at Watervliet Arsenal was surveyed for infrared hazards on 9-10 March 1978. It was found that levels of infrared exceeding protection standards for 10-second exposures were present at distances less than approximately 3 meters from the radiation source. This radiation would, however, be easily detected by exposed personnel due to body heating and would not, therefore, present a serious health hazard due to whole-body heating. However, eye protection against infrared was deemed necessary due to possible cataract formation from repeated exposures. It was recommended that infrared eye protection be provided to workers and that a Safety Standing Operating Procedure be established to minimize infrared exposure.

FOR THE COMMANDER:

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NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-0360-78
INFRARED RADIATION HAZARD
EVALUATION OF THE ROTARY FORGE
WATERVLIET ARSENAL
WATERVLIET, NEW YORK
MARCH - APRIL 1978

1. AUTHORITY. Letter, SARWV-XO, Watervliet Arsenal, 9 December 1977, subject: Rotary Forge Special Industrial Hygiene Survey.

2. REFERENCES. See Appendix A for a listing of references.

3. PURPOSE. The purpose of this study was to evaluate potential infrared hazards associated with the use of the rotary forge at Watervliet Arsenal, and to make recommendations necessary to prevent exposure of personnel to hazardous levels of optical radiation.

4. GENERAL.

a. Background. Watervliet Arsenal requested that this Agency perform an industrial hygiene survey of the rotary forge operation, including a study of the infrared hazards. The rotary forge was developed by Gesellschaft für Fertigungstechnik and Maschinenbau (GFM) in Steyr, Austria. The integrated production line was designed primarily for the hot forging of thick-wall cannon tubes of various sizes. The process consisted of induction heating of ingots or preformed tubes to approximately 1800°F (1255°K), rotary forging the tubes into desired configuration, heat treating the tubes, and machining the tubes to final specifications. At the time of the study, the equipment was not operating in a production mode. Research and Engineering (R&E) personnel were training operating personnel, and process variables were being altered to determine optimum operating parameters and procedures. A photograph of the rotary forge in operation is provided as Figure 1.

b. Instrumentation.

(1) United Detector Technology, Inc. Model 40A Optometer.

(2) Laser Precision Model RK3440 Pyroelectric Radiometer.

(3) Water filter.

(4) Photo Research Model 1980P Photometer.

c. Abbreviations and Definitions. A list of commonly used radiometric terms and units, with their abbreviations, is supplied in Appendix B.

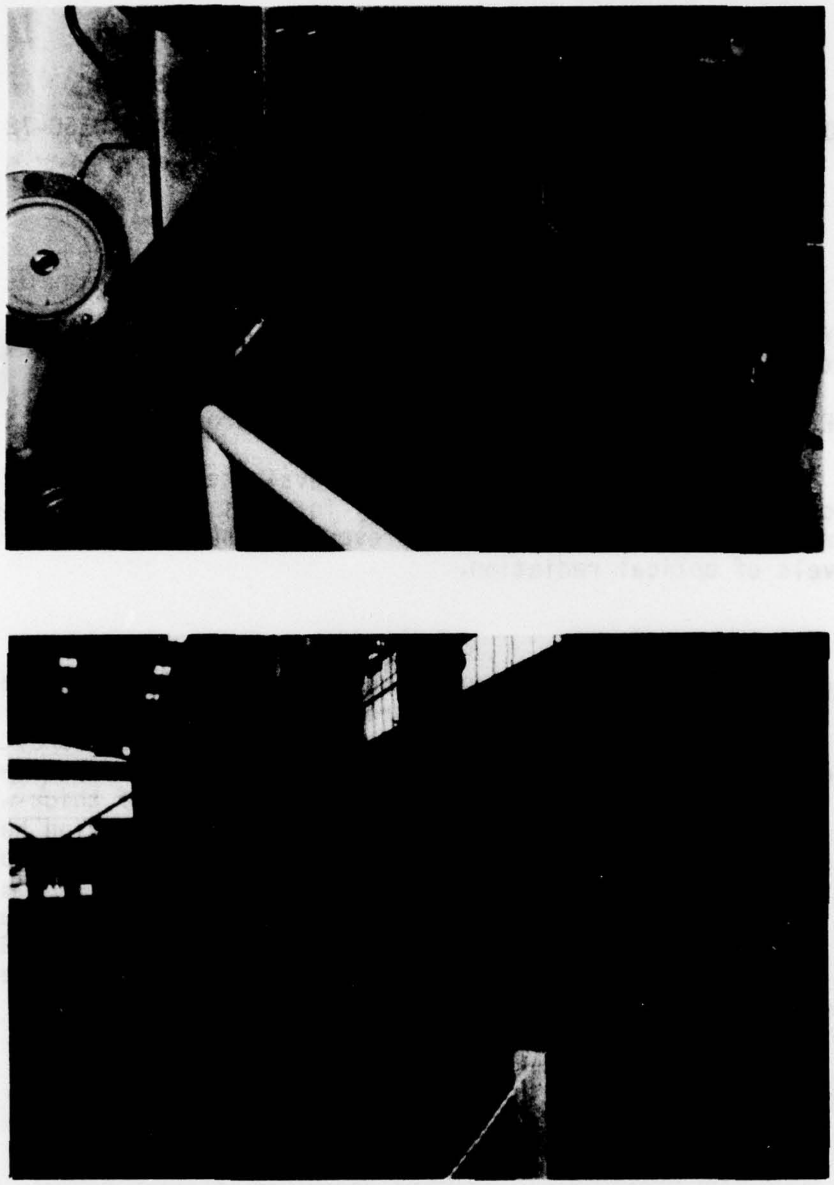

Figure 1. Photographs of the Rotary Forge in Operation. Upper photograph shows the cannon tube being formed in the hammers. Lower photograph shows the finished tube being positioned in the cooling rack.

5. FINDINGS.

a. Description of Operation.

(1) Loading the Forge. The hot metal cylinder, which would become a cannon tube, was loaded out of the induction furnace at about 980°C (1800°F) and into an enclosed wheeled transporter which moved the billet laterally to a set of rollers. The billet was then slowly pushed out onto the rollers (25-30 s). As soon as the billet was loaded onto the rollers, it moved very quickly across the rollers (approximately 1-2 s) and was then loaded into the moveable chuck heads. Personnel could be located very near to the billet during this transfer process, although such close proximity was not required for proper operation. Sufficient space was not available for a permanent work area between the rollers and the induction furnace.

(2) Forging. The billet was moved back and forth and rotated in the hammer box of the rotary forge by the moveable chuck heads. The billet was hammered by four hammers in an automatic sequence of movements until the cylinder had achieved the proper length and diameter. During this operation, the billet was visible on either side of the forge from time to time. A guard rail was set up around the work area which kept personnel approximately 1.2 m (4 ft) away from the workpiece. Although personnel would not normally be required near the partially-finished cannon tube, several (four or five) persons were observed viewing the billet at close distances (1-2 m) in order to determine the cause of some malfunction in the forge during the US Army Environmental Hygiene Agency (USAEHA) visit.

(3) Unloading the Forge. The hot, forged cannon tube was lifted by an overhead crane to a cooling rack located approximately 20 m from the forge. A workman was required to guide the hot cannon tube to the proper position in the cooling rack.

(4) Cooling Rack. The cooling rack was approximately 12 m in length and 5 m in width. There were provisions for the cooling of 16 cannon tubes (each 5 m in length) equally spaced along the length of the rack. Although only one space was filled during the visit by USAEHA personnel, the entire rack could be filled during production operation. The tubes would then be in various stages of cooling.

b. USAEHA Measurements.

(1) Far infrared (IR). Measurements of far IR (IR-B and IR-C bands) were made with the RK3440 radiometer which has a responsivity in the spectral region from 300 nm to 20 μm and a field of view of approximately 14°. A level of 130 mW/cm^2, through a 14° cone angle, was measured 1.2 m from the cannon tube as it was loaded onto the rollers from the induction furnace. Since the source was so large, the actual cosine-corrected irradiance at this

point was greater than 1.0 W/cm^2. Measurements at the same distance during forging indicated 86 mW/cm^2 through a 14° cone angle. Due to the differing configuration, the cosine-corrected level was approximately 200-300 mW/cm^2 in this area. At 2-3 m from the radiation source, the level would be about 100 mW/cm^2. Figure 2 shows the approximate cosine-corrected levels at various distances from the edge of the cooling rack with one tube, and the predicted levels expected when the rack is half-full (eight tubes).

(2) Safety Glass Transmission. Transmission measurements were taken on both plastic safety glasses and glass safety glasses available at Watervliet during the study. Measurements were made using the hot cannon tube as a radiation source and the RK3440 as a detector. Eleven percent was transmitted through the plastic goggles. Thirty-seven percent was transmitted through glass safety goggles. Transmission measurements of other available materials were made using a lamp which simulated a 1000°C (1275°K) blackbody. These results are provided in Appendix C.

(3) Radiation from the Cooling Rack. Measurements were taken on only one cannon tube in the cooling rack. During production runs, the rack may have as many as 16 tubes in various stages of cooling. Radiation levels in excess of 100 mW/cm^2 may be present 6-7 m from the edge of the rack when it is half-full or more. Therefore, personnel would encounter heat stress within minutes in this area.

c. Cooling Fans. Powerful cooling fans and large vents were installed to remove excess heat buildup during summer operation. These fans were designed to keep down ambient temperature levels. Radiation levels will not be directly affected, however, by the use of these fans.

6. DISCUSSION.

a. Far IR Radiation.

(1) Protection Standard. The protection standard for far-IR (IR-B and IR-C) radiation is the same for lasers and extended sources. The protection standard (Table 2-2, AR 40-46) for exposures greater than 10 s is 100 mW/cm^2. This level is used for protection for both eyes and skin, but does not assume whole-body exposure. Heat-stress indices apply in addition to the 100 mW/cm^2 limit.

(2) Eye Exposure. Although radiation at the protection standard level is not considered hazardous for infrequent exposure to the eyes, repeated exposures such as may occur in this work environment may be instrumental in the formation of glassblower's cataracts. At the time of this study, sufficient biological data on cataract production were not available to assure that even the permissible exposure levels for chronic, repeated occupational exposure were sufficiently conservative. Therefore, additional protection for the eyes was deemed necessary.

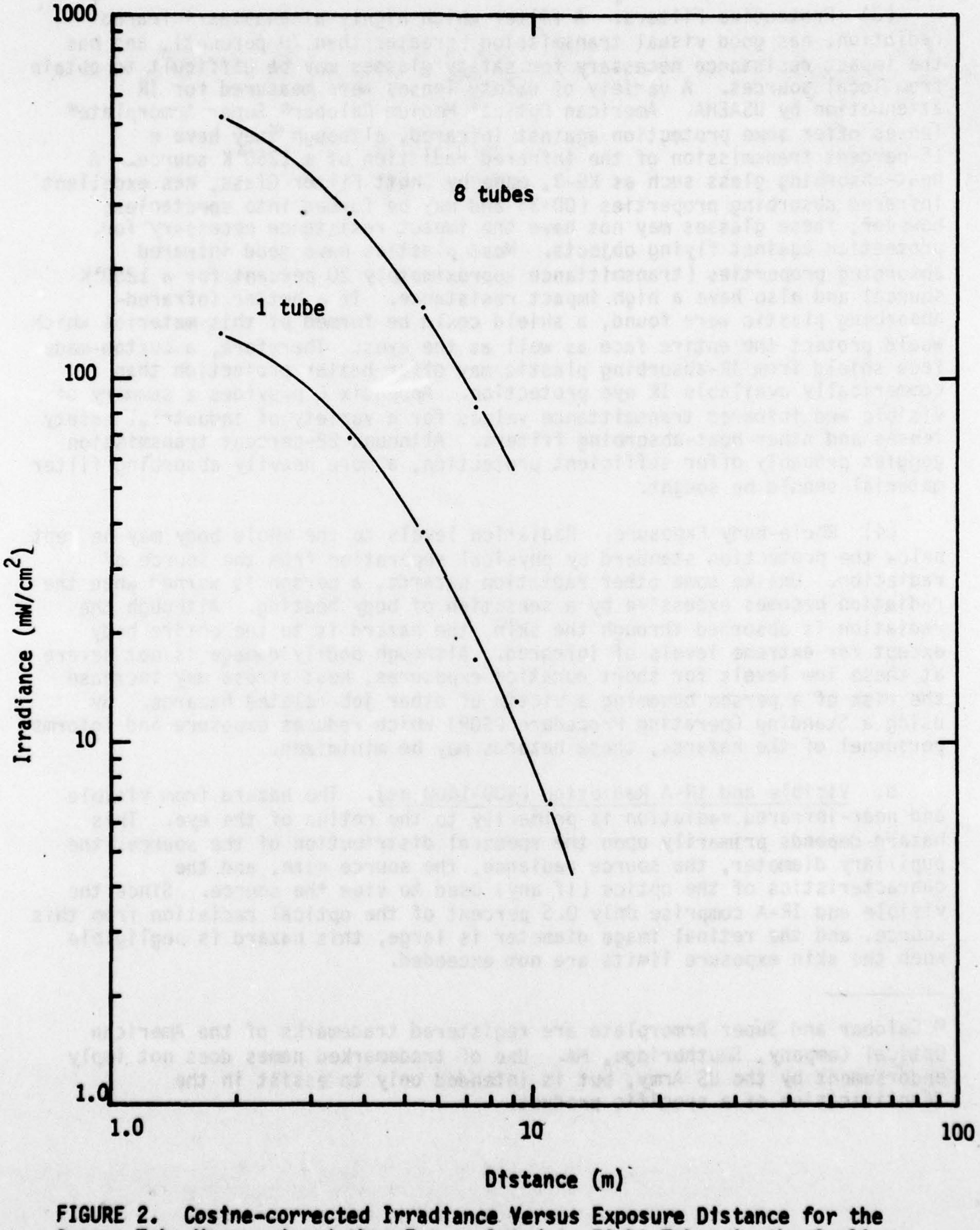

FIGURE 2. Cosine-corrected Irradiance Versus Exposure Distance for the Cannon Tube Measured and then Extrapolated to Eight Tubes in the Cooling Rack.

(3) Protective Filters. A filter which highly attenuates infrared radiation, has good visual transmission (greater than 70 percent), and has the impact resistance necessary for safety glasses may be difficult to obtain from local sources. A variety of safety lenses were measured for IR attenuation by USAEHA. American Optical Medium Calobar® Super Armorplate® lenses offer some protection against infrared, although they have a 15-percent transmission of the infrared radiation of a 1250°K source. A heat-absorbing glass such as KG-3, made by Shott Filter Glass, has excellent infrared absorbing properties (OD>3) and may be formed into spectacles; however, these glasses may not have the impact resistance necessary for protection against flying objects. Most plastics have good infrared absorbing properties (transmittance approximately 20 percent for a 1250°K source) and also have a high impact resistance. If a better infrared-absorbing plastic were found, a shield could be formed of this material which would protect the entire face as well as the eyes. Therefore, a custom-made face shield from IR-absorbing plastic may offer better protection than commerically available IR eye protection. Appendix C provides a summary of visible and infrared transmittance values for a variety of industrial safety lenses and other heat-absorbing filters. Although 22-percent transmission goggles probably offer sufficient protection, a more heavily absorbing filter material should be sought.

(4) Whole-body Exposure. Radiation levels to the whole body may be kept below the protection standard by physical separation from the source of radiation. Unlike some other radiation hazards, a person is warned when the radiation becomes excessive by a sensation of body heating. Although the radiation is absorbed through the skin, the hazard is to the entire body except for extreme levels of infrared. Although bodily damage is not severe at these low levels for short duration exposures, heat stress may increase the risk of a person becoming a victim of other job-related hazards. By using a Standing Operating Procedure (SOP) which reduces exposure and informs personnel of the hazards, these hazards may be minimized.

b. Visible and IR-A Radiation (400-1400 nm). The hazard from visible and near-infrared radiation is primarily to the retina of the eye. This hazard depends primarily upon the spectral distribution of the source, the pupillary diameter, the source radiance, the source size, and the characteristics of the optics (if any) used to view the source. Since the visible and IR-A comprise only 0.5 percent of the optical radiation from this source, and the retinal image diameter is large, this hazard is negligible when the skin exposure limits are not exceeded.

® Calobar and Super Armorplate are registered trademarks of the American Optical Company, Southbridge, MA. Use of trademarked names does not imply endorsement by the US Army, but is intended only to assist in the identification of a specific product.

7. CONCLUSION. The rotary forge at Watervliet Arsenal emits levels of infrared exceeding current protection standards. However, the forge hazards may be controlled, provided that appropriate control precautions are taken.

8. RECOMMENDATIONS.

a. Provide eye protection against infrared to personnel working in the immediate vicinity of the forge or cooling rack during operation. Protection for a passerby is not necessary [paragraph 1-5d(3), AR 40-46].

b. Develop an SOP which will minimize exposure to infrared radiation [paragraph 1-5d(2), AR 40-46].

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APPENDIX A

REFERENCES

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2. AR 40-5, Health and Environment, 25 September 1974.

3. AR 40-46, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, 6 February 1974.

4. TB MED 175, The Etiology, Prevention, Diagnosis, and Treatment of Adverse Effects of Heat, 25 April 1969.

5. Letter, HSE-OM, this Agency, 31 January 1978, subject: Occupational Health (OS), Occupational Vision (OV), Industrial Hygiene (IZ), and Non-ionizing Radiation Protection (NL) surveys, Watervliet Arsenal.

APPENDIX B

USEFUL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS[1, 2]

RADIOMETRIC				PHOTOMETRIC			
Term	**Symbol**	**Defining Equation**	**SI Unit and Abbreviation**	**Term**	**Symbol**	**Defining Equation**	**SI Units and Abbreviation**
Radiant Energy	Q_e		Joule (J)	Quantity of Light	Q_v	$Q_v = \int \Phi_v dt$	lumen-second (lm·s) (talbot)
Radiant Energy Density	W_e	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter ($J \cdot m^{-3}$)	Luminous Energy Density	W_v	$W_v = \frac{dQ_v}{dV}$	talbot per square meter ($lm \cdot s \cdot m^{-3}$)
Radiant Power (Radiant Flux)	Φ_e, P	$\Phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux	Φ_v	$\Phi_v = 680 \int \frac{d\Phi_e}{d\lambda} V(\lambda)\, d\lambda$	lumen (lm)
Radiant Exitance	M_e	$M_e = \frac{d\Phi_e}{dA} = \int L_e \cdot \cos\theta \cdot d\Omega$	Watt per square meter ($W \cdot m^{-2}$)	Luminous Exitance	M_v	$M_v = \frac{d\Phi_v}{dA} = \int L_v \cdot \cos\theta \cdot d\Omega$	lumen per square meter $lm \cdot m^{-2}$
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	E_e	$E_e = \frac{d\Phi_e}{dA}$	Watt per square meter ($W \cdot m^{-2}$)	Illuminance (luminous flux density)	E_v	$E_v = \frac{d\Phi_v}{dA}$	lumen per square meter ($lm \cdot m^{-2}$) lux (lx)
Radiant Intensity	I_e	$I_e = \frac{d\Phi_e}{d\Omega}$	Watt per steradian ($W \cdot sr^{-1}$)	Luminous Intensity (candlepower)	I_v	$I_v = \frac{d\Phi_v}{d\Omega}$	lumen per steradian (lm·sr) or candela (cd)
Radiance	L_e	$L_e = \frac{d^2\Phi_e}{d\Omega \cdot dA \cdot \cos\theta}$ [5]	Watt per steradian and per square meter ($W \cdot sr^{-1} \cdot m^{-2}$)	Luminance	L_v	$L_v = \frac{d^2\Phi_e}{d\Omega \cdot dA \cdot \cos\theta}$ [5]	candela per square meter ($cd \cdot m^{-1}$)
Radiant Exposure (Dose, in Photobiology)	H_e	$H_e = \frac{dQ_e}{dA}$	Joule per square meter ($J \cdot m^{-2}$)	Light Exposure	H_v	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx·s)
				Luminous Efficacy (of radiation)	K	$K = \frac{\Phi_v}{\Phi_e}$	lumen per watt ($lm \cdot W^{-1}$)
				Luminous Efficiency (of a broad band radiation)	$V(*)$	$V(*) = \frac{K}{K_m} = \frac{K}{680}$	unitless
Radiant Efficiency [3] (of a source)	η_e	$\eta_e = \frac{P}{P_i}$	unitless	Luminous Efficacy[3] (of a source)	η_v	$\eta_v = \frac{\Phi_v}{P_i}$	lumen per watt ($lm \cdot W^{-1}$)
Optical Density [4]	D_e	$D_e = -\log_{10} \tau_e$	unitless	Optical Density[4]	D_v	$D_v = -\log_{10} \tau_v$	unitless
				Retinal Illuminance in Trolands	E_t	$E_t = \frac{L_v}{S_p}$	troland (td) = luminance in $cd \cdot m^{-2}$ times pupil area in mm^2

1. The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript λ. For example, spectral irradiance H_λ has units of $W \cdot m^{-2} \cdot m^{-1}$ or more often, $W \cdot cm^{-2} \cdot nm^{-1}$.

2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or μm are most commonly used to express wavelength.

3. P_i is electrical input power in watts.

4. τ is the transmission

5. At the source $L = \frac{dI}{dA \cdot \cos\theta}$ and at a receptor $L = \frac{dE}{d\Omega}$

APPENDIX C

IR TRANSMISSION AND VISUAL TRANSMISSION OF VARIOUS EYE-PROTECTIVE FILTERS

1. The transmission values in the following Table were measured against a lamp having a black-body curve associated with a temperature of 1250°K for IR emission. The visual transmission values were measured using the sun as a 6500°K source and a photopic filter to simulate the response of the eye. Some of the following filters are available in darker or lighter shades, although only one or more shades were measured.

TABLE. FILTER TRANSMISSION VALUES

Filter	Infrared Transmission (Percent)	Visible Transmission (Percent)
American Optical		
Clear	53	91
Cruxite	60	82
Didymium	46	48
MD Calobar	15	52
True Color	21	21
Cobalt blue	32	0.74
Dark Calobar	9.4	37
Noviol	69	88
Plastic	22	94
Extra Dark Calobar	0.56	6.2
Filterweld	2.4	20
AO 584 Laser Goggle	6.3	36
Polysnap	29	92
Schott		
KG 3-1 mm	7.1	86
BG-18 -3 mm	12	32
KG 3-6.5 mm	<0.5	56
3M EC Coatings		
A33	12	32
A18	4.8	16
Eastern Safety *		
Visitors' Goggles	22	91
Safety Visor	22	91
Glendale Optical		
Glenweld Shade 1.3	20	67

*Characteristic of all clear plastic safety eyewear.

2. The spectral transmittance values of some infrared (IR) reflective coatings are provided in the following Figure.

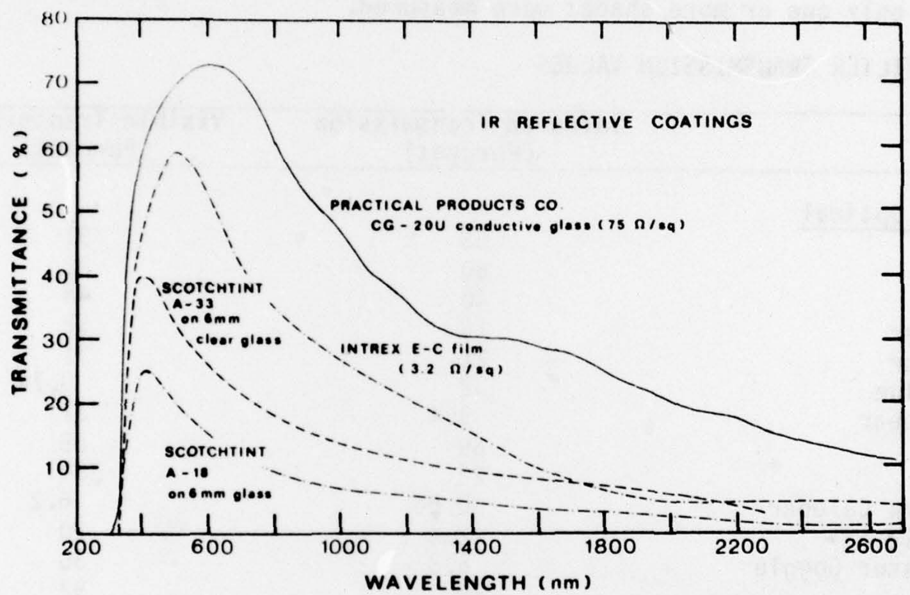

Figure. IR Reflective Coatings

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Laser Hazards Bibliography

Laser Protective Eyewear

Questions and Answers on Laser Rangefinder Hazards

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